Physicochemical and Optical Characterization of Aerosol Fields from Coastal Breaking Waves

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LONG-TERM GOAL

Our long term goal is to establish an improved understanding of the properties and factors that control the coastal surf zone aerosol generation processes, their dependence on oceanic and environmental conditions and aerosol evolution in transition from pure marine to coastal environment.

OBJECTIVES

Our intent is to establish a predictive capability for the size distribution of aerosol produced under various conditions, its 3-D spatial structure and associated optical effects. The focus for our study is the relation of coastal aerosol optical properties and spectral visual range. Our intent is to assess the modifications of the offshore aerosol through interactions with coastal sources and its response to various environmental factors.

APPROACH

This year we focused on analysis of breaking waves in a coastal setting through measurement of the complete size spectra from 0.007 to 20µm using a suite of instruments operating at both dry and ambient conditions. Measurements were carried out at our Bellows Air Force Base (BAFB) site with its 20m tower (SEAS experiment) and Meleakehana (RED experiment). Optical properties and size distributions were compared and lower boundary layer structure and visibility has been characterized with our established instrumentation along with the a Vaisala Ceilometer and Visibility Sensor.

WORK COMPLETED (2001-2002)

This year our studies included the final analysis of the ONR Shoreline Environmental Aerosol Study (SEAS 2000) (Clarke et al., 2002a,b, Masonis et al., Campuzano-Jost et al.); the analysis of the ONR Rough Evaporating Duct Study (RED 2001) (Clarke et al. 2002c) and our development and testing of new aerosol instrumentation – miniOPC. A paper on the mini-OPC is now in press in the Journal of Atmospheric and Oceanic technology. SEAS data were analyzed in collaboration with the UH lidar

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14. ABSTRACT
Our long term goal is to establish an improved understanding of the properties and factors that control the coastal surf zone aerosol generation processes, their dependence on oceanic and environmental conditions and aerosol evolution in transition from pure marine to coastal environment.

15. SUBJECT TERMS

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group (Lienert et al., Porter et al.), University of Washington (Masonis et al.), University of Miami (Campuzano-Jost et al.) and Oregon State University (Shifrin et al.) groups. Seven SEAS related papers were submitted to Journal of Atmospheric and Oceanic Technology in 2002.

RESULTS

SEAS Experiment: Marine aerosol influenced by a coastal environment and long-range transport

SEAS was carried out in Hawaii on the east coast of Oahu exposed to relatively steady onshore flow. This location provided favorable opportunities to test and evaluate new instrumentation designed to improve measurements of marine aerosol and their physical, chemical and optical properties including the remote sensing (lidar) of coastal aerosol fields.

SEAS included measurements of the aerosol lidar backscatter coefficient (Masonis et al.), the aerosol phase function (Lienert et al.); size-resolved sodium chemistry on single particles (Campuzano-Jost et al.); 3-D scanning lidar system (Porter et al.) and our measurements (Clarke et al., 2002a,b).

Under typical trade-wind conditions the aerosol was usually dominated by the production of sea-salt aerosol from open-ocean breaking waves that contribute most mass to the super-micrometer size range and significantly affect visible and infrared light extinction over the open ocean. At 5m above sea level and 20m inland from the waters edge the sea-salt nuclei number were often in the range 50 to 100 cm^{-3} above the background value of 250 cm^{-3}. This number peak was near 30nm dry diameter (DMA data - not shown) while light scattering was dominated by particles larger than 1um. These thermal DMA measurements demonstrated that sea-salt production contributes not only to aerosol mass and optical effects but also to nuclei mode particle number.

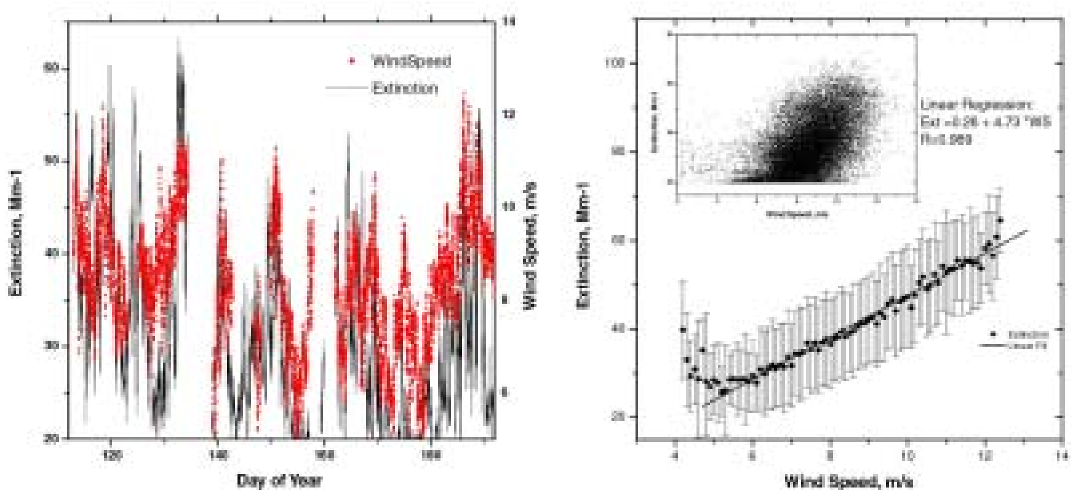

Figure 1. a) time series of wind speed and filtered minimum extinction at BAFS over 80 days and b) relationship between average scatter for binned wind speed (see text).

Because open-ocean breaking waves are driven by surface wind speeds then we expect light scattering and wind speeds to be related in regions where aerosol removal (e.g. precipitation) is not a strong and variable factor. Figure 1a shows the time series of wind speed and filtered scattering extinction from the Vaisala visibility sensor located at about 15m on the sample tower. These data for 80 days that

include the SEAS period (DOY 110-120) demonstrate that long period variations in extinction are coupled to variations in wind speed. A scatterplot of this data for the 80 day period [insert in Fig. 1b] reveal a mean slope indicative of a wind speed dependence but with scatter indicative of other process influencing extinction. The mean and standard deviation of observed extinction for each binned interval of 0.1 ms^{-1} of wind speed [Fig. 1b] shows a clear dependence of extinction on wind speed between 6 and 12 m/s. Below 6 m/s extinction is higher than this dependence would suggest. This may be due in part to limitations of the visibility sensor under low extinction conditions but also to the general increase in coastal aerosol concentrations under low wind conditions caused by less dilution of aerosol produced from coastal breaking waves. This figure reveals that increased wind speed is a major influence on coastal light scattering but with large variability resulting from other influences.

SEAS measurements were focused on the coastal aerosol size distribution and related optical measurements including aerosol light scattering, visibility and remote sensing of aerosol using lidar backscatter. Aerosol production from breaking waves was characterized for dry sizes between 10 and 10,000 nm both for their contribution to the marine aerosol population and their influence on near surface lidar extinction. Thermal volatility was used to extract the refractory sea-salt particles from the other constituents volatile at 360C.

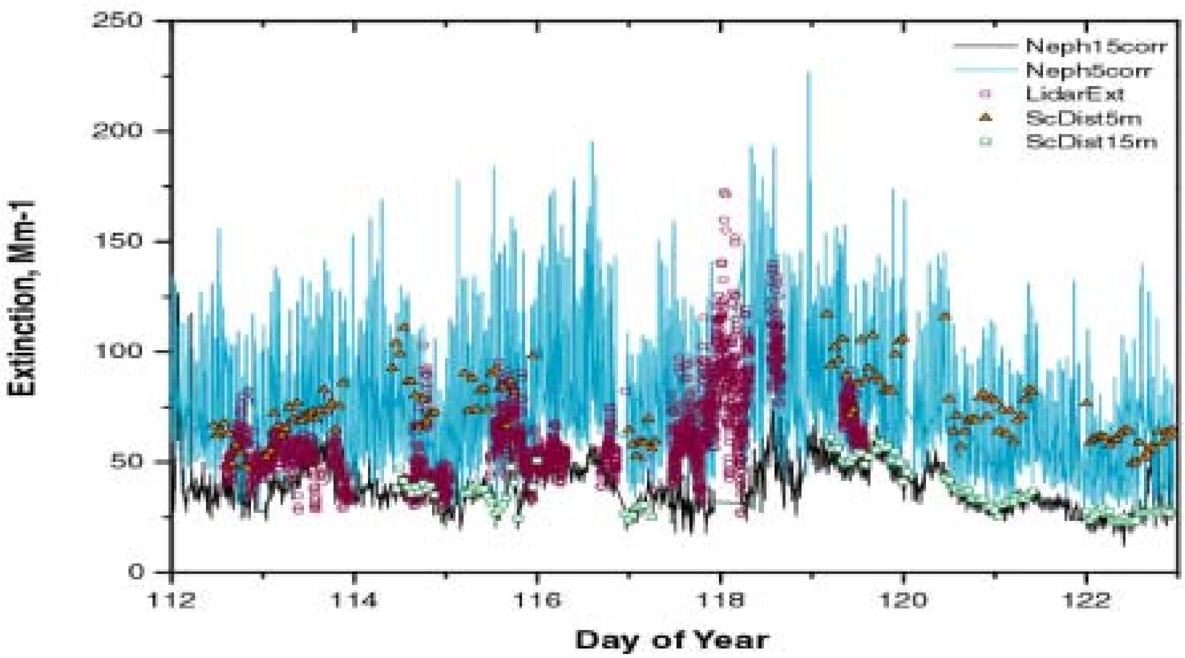

Figure 2. SEAS time series of 5m and 15m tower extinction data corrected to ambient conditions (thin lines) with corresponding extinction calculated with 20min averages from size distribution (boxes) compared to variations in lidar extinction observed 300-400m offshore from 0-25m (circles).

Figure 2 shows UH nephelometer data at 5m (Neph5corr) and 15m(Neph15corr) on the coastal tower corrected to obtain expected ambient scattering extinction after allowing for angular truncation, sampling losses and f(RH) for the SEAS period (Clarke et al. 2002b). Continuous scattering data at 5m reveal the high values and large variability associated with intermittent breaking waves compared to lower and less variable data for 15m. Extinction values calculated from the size distributions taken from 5m and 15m (ScDist5m and ScDist15m) and corrected to ambient conditions (green squares) agree well with the ambient corrected nephelometer values. The size-derived extinction at 5m (20

min avg.) for breaking waves (triangles) also often show good agreement and are generally centered on the excursions in the 5m nephelometer data. Lidar extinction data (5s avg. taken every 2 minutes - open circles) from the lidar swath [25m by 100m] at 300m upwind of the site are also shown. The lower envelope of many lidar values fall near the 15m extinction values obtained from the size distributions and nephelometer extinction data. Frequently lidar values show excursions to somewhat higher values in these periods that are not seen in the 15m tower data but fall within the highly variable 1-2 min nephelometer extinction peaks measured at 5m and close to the averaged (20min) size-distribution extinction at 5m. These reveal the contribution of reef produced plumes to the lidar extinction at 300m and quantify links between the size distribution and optical scattering measurements, visibility and extinction values for nearshore breaking waves and open ocean conditions. These data confirmed that extinction values derived from coastal lidar measurements at 530nm were within the 35% uncertainty claimed for both background for breaking wave conditions.

RED experiment: The Contribution of Coastal Aerosol From Breaking Waves to Visible and IR Light-Extinction Over 10 Km Path

The Rough Evaporation Duct (RED) experiment was off the NE coast of Oahu, Hawaii in August-September of 2001. A 10km electro-optic (EO) path between the R/V FLIP and a receiver on the coast passed over a near shore region of frequent breaking waves about 500m in front of the detector. Marine aerosol produced from these breaking waves varied in intensity of production and their influence on the EO signal depending upon environmental factors including wind direction (see Figure 3).

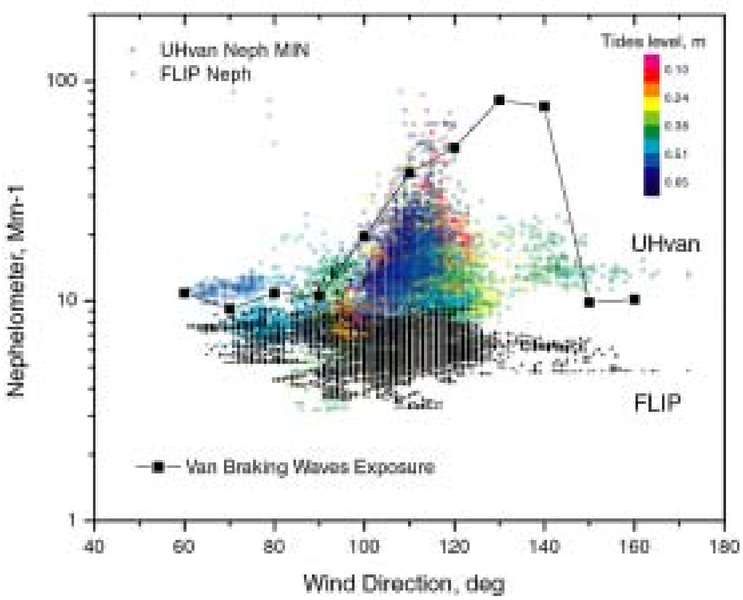

Figure 3. Comparison of FLIP Scatter (black) and UH Van scatter (colored) vs. Wind Direction and estimated coastal breaking wave exposure (black squares) during RED. Exposure is linear dimensionless estimate of relative typical upwind coastal area generating aerosol at van. Similar exposure for EO cabin is greater and peaks 90-110 deg.

Because the EO path passed only about 2m above the surface these aerosol usually intercepted the EO path over some distance. Our UH aerosol research van (UHV) was located about 400m toward FLIP from the EO detector and about 100m north of the EO path. This meant the UHV sampled open-ocean

aerosol unless more southerly winds brought aerosol from the breaking wave region upwind of the EO detector. The latter cases had far higher extinction values, allowing us to distinguish the influence of these waves upon the RED EO path extinction. Our UHV measurements included the aerosol size distribution from 10nm to over 10um in conjunction with optical measurements including aerosol light scattering and light absorption. The sample mast was also removed for a period to get the near surface size-distributions at 3m altitude and concurrent extinction data for interpretation of similar values for the near surface EO path (see Figure 4). Analysis of the coastal geometry and the wind speeds were used to estimate the impact of both the open ocean aerosol and the contributions of aerosol from breaking waves upon the 10km EO signal.

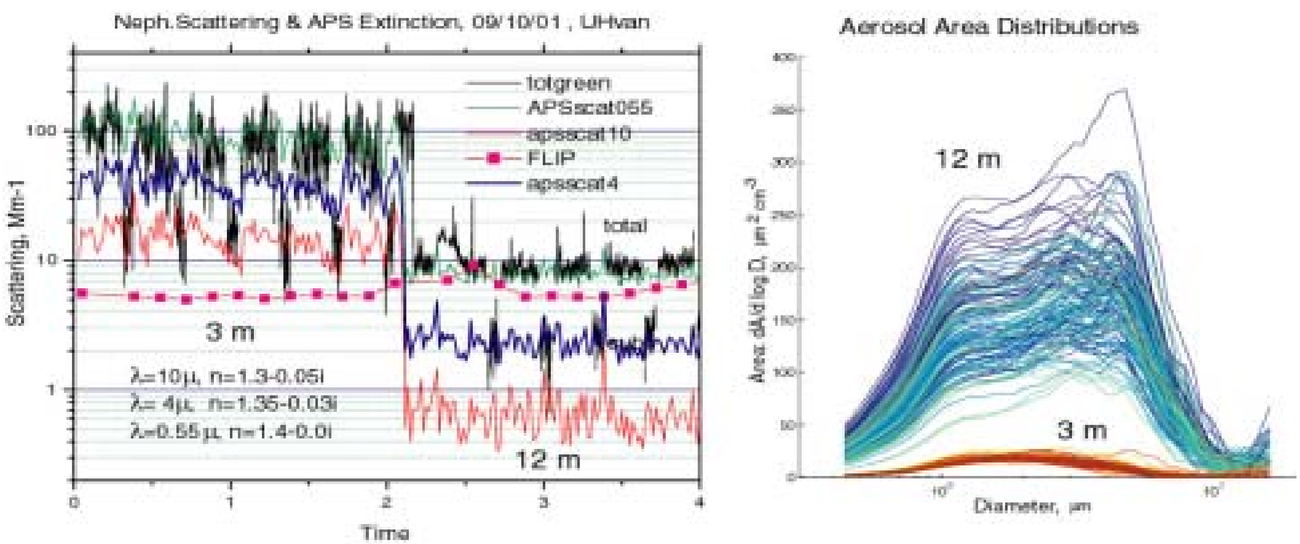

Figure 4. Comparison of sampling switched from 3m vs. 12m for UH Van for wind at about 100deg. a. Modeled extinction in visible (0.55um) and IR (4 and 10um) at 3m and 12m compared to measured (excellent agreement for measured and modeled data, over an order of magnitude greater extinction for 3m aerosol in 10um IR); b. Aerosol area distributions at 3m and 12m

IMPACT/APPLICATION

Our new mini-OPC was demonstrated (publication) to be an effective new tool for aerosol measurements. Our observations of sub-100nm sea-salt aerosol will lead to revised understanding of sea-salt production. SEAS highlighted new approaches for calibration of lidars and to derive aerosol extinction values. Size distribution data and Visibility and Ceilometer data have been compared to provide a sound physical basis for their interpretation in terms of aerosol extinction. RED aerosol data allowed estimate the effect of coastal aerosol from breaking waves on visible and IR EO propagation.

RELATED PROJECTS

Our SEAS measurements are directly linked with Dr. S. K. Sharma's Lidar project ONR #N000149610317, Dr. K. S. Shifrin ONR project # N000149810773 and Dr. J. N. Porter's radiation project NASA-NAG-56340. Our RED coastal measurements are directly linked with Dr. K.D. Anderson Electromagnetic Propagation project ONR #N0001401WX20195 and other RED related projects. The mini-OPC tests contributed to and were also partially supported by activities under our NASA-TRACE-P funding (NCC-1-416).

PUBLICATIONS

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